

21st International Workshop on Laser Ranging

ILRS: Current Status and Future Plans

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Abstract

The International Laser Ranging Service (ILRS) has supported the global scientific community for twenty years, coordinating laser ranging observations to a diverse set of orbiting satellites equipped with retroreflectors. In recent years, the service has faced several challenges, most notably an aging network tasked to support an ever-increasing list of targets. Progress is being made in several areas. The ILRS network is expanding with new stations and upgrades to current stations. Capabilities are evolving, including stations with higher repetition rates and more efficient detection to better enable interleaving of satellite passes. New GNSS constellations, as well as other retroreflector-equipped satellites, now bring the total roster to over 100 satellites, requiring the ILRS to consider new tracking strategies. New applications of one-way and two-way laser ranging include ps-accurate time transfer and laser transponders for interplanetary ranging. Analysis centers continue refining ILRS data products, including satellite orientation, gravity field products, and characterizations of the quality of data and station performance.

This talk will summarize current status, recent progress, upcoming challenges, and plans for the future of the ILRS.

1. Introduction

Laser ranging activities around the world are organized under the International Laser Ranging Service (ILRS) which provides global satellite and lunar laser ranging data and their derived data products to support research in geodesy, geophysics, lunar science, and fundamental physics (About the ILRS, 2019). These efforts include the generation of data products that are fundamental to the International Terrestrial Reference Frame (ITRF), which is established and maintained by the International Earth Rotation and Reference Systems Service (IERS).

The ILRS is one of the space geodetic services of the International Association of Geodesy (IAG) and is a member of the IAG's Global Geodetic Observing System (GGOS). The services, under the umbrella of GGOS, provide the geodetic infrastructure necessary for monitoring global change in the Earth system (Beutler and Rummel, 2012).

These collected SLR data sets are of sufficient quality to support many scientific and operational applications including:

- Realization of global accessibility to and the improvement of the ITRF
- Monitoring three dimensional deformations of the solid Earth
- Monitoring Earth rotation and polar motion
- Supporting missions monitoring variations in the topography and volume of the fluid Earth (ocean circulation, mean sea level, ice sheet thickness, wave heights, etc.)
- Tidally generated variations in atmospheric mass distribution

- Calibration of microwave tracking techniques
- Picosecond global time transfer experiments
- Astrometric observations including determination of the dynamic equinox, obliquity of the ecliptic, and the precession constant
- Gravitational and general relativistic studies including Einstein's Equivalence Principle, the Robertson-Walker b parameter, and time rate of change of the gravitational constant
- Lunar physics including the dissipation of rotational energy, shape of the core-mantle boundary (Love Number k_2), and free librations and stimulating mechanisms
- Solar system ties to the International Celestial Reference Frame (ICRF)

Recent developments within the ILRS infrastructure are reviewed here. However, advances in scientific analysis and ILRS official products were discussed in other presentations at the workshop.

2. Recent Updates

The ILRS Governing Board is responsible for the direction of the ILRS, exercising general control and review over the activities of the service. The composition of the board includes ex-officio members, members selected from the three regional networks, members elected by their peers within the ILRS components, and members appointed by the board. According to the Terms of Reference, board elections are held every two years. During 2018, an election was conducted for the members to serve on the board for the 2019-2020 term. The new board took office, with the exception of the two board-appointed positions, at the 21st International Workshop on Laser Ranging; at their meeting, Toshi Otsubo of the Hitotsubashi University in Tokyo, Japan was elected as ILRS Governing Board chair. An election process will be held in early 2019 for the two board-appointed positions.

The Journal of Geodesy recently issued a call for contributions to a Special Issue on Laser Ranging. The publication is currently in process with over 10 papers accepted for publication and another so many still under review. The special issue will be an important contribution to the community covering among other topics, scientific analysis and research, engineering development, and operational aspects in the laser ranging field.

3. Current Trends

Presentations and posters at the workshop covered important scientific and engineering advances in laser ranging. New lasers with narrower pulse widths, and higher (e.g. kHz) repetition rates, coupled with single-photon detectors and event timers, have brought improvements in data precision, data acquisition speeds, and pass interleaving; Figure 1 shows that stations are very busy and use pass interleaving to increase productivity. Experience and refined procedures have increased performance on GNSS and other high satellites. Stations are also implementing software for real-time data evaluation and decision making for tracking, and for rapid communication and information-sharing among stations. Implementation of automation techniques at stations is permitting more efficient operation and remote access, thus decreasing on-site staffing requirements while increasing productivity. Improvements in environmental monitoring capabilities and awareness permit safer operation and enhanced instrument

integrity. In the space segment, missions are testing and installing denser arrays with smaller cubes to help reduce the RMS of the return signal.

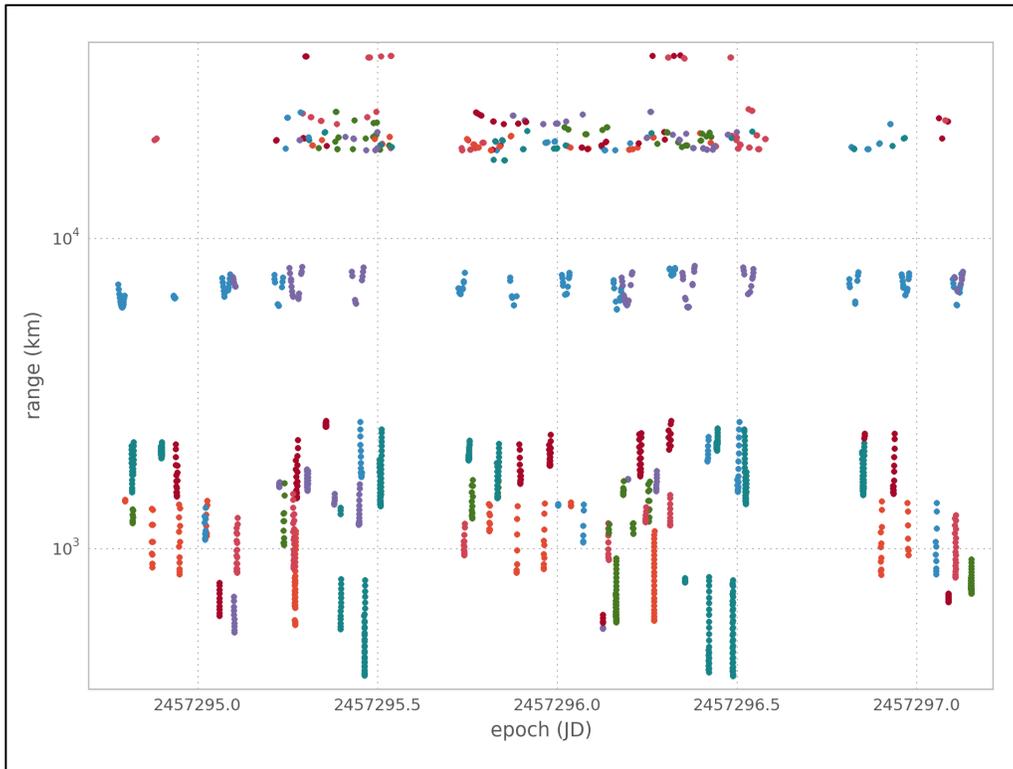


Figure 1. An example of pass interleaving capabilities at Herstmonceux in 2015 (figure credit: Graham Appleby/NSGF).

4. ILRS Network

The current network supporting the ILRS includes 39 operational stations as shown in Figure 2. Figure 3 presents the data yield from the ILRS network, providing evidence of the network's continued upward trend over recent years. In 2018, these stations tracked 126 satellites generating 187K passes of data with nearly 2M normal points. A new Russian laser system became operational in Hartebeesthoek, South Africa, co-located with the existing NASA system. A comparison of these systems is currently underway. The Russian agencies are pursuing future installations in Ensenada (Mexico), Java (Indonesia), and Canary Islands (Spain). Some additional options for co-locations are under discussion. New and upgraded SLR systems by other groups are nearing completion. An upgraded TIGO system moved from Concepción, Chile and should be operational soon, as part of the new Argentinean-German Geodetic Observatory (AGGO) core site in La Plata, Argentina. NASA's Space Geodesy Project (SGP) is proceeding with the fabrication and installation of the SGSLR as part of upgraded core sites at McDonald, TX and Haleakala, HI (USA) in the next two to four years, and in cooperation with the Norwegian Mapping Agency (NMA) for an SGSLR installation as part of the new core site in Ny Ålesund (Norway) in the same time frame. Other new stations on the horizon to become operational in the next year or two include Metsahovi (Finland), Mt. Abu and Ponmundi (India), and Yebes (Spain).

Although new SLR site installations are planned over the next few years, as illustrated in Figure 2, large gaps in the geographic coverage of the ILRS network still exist, providing great opportunities for new partners.

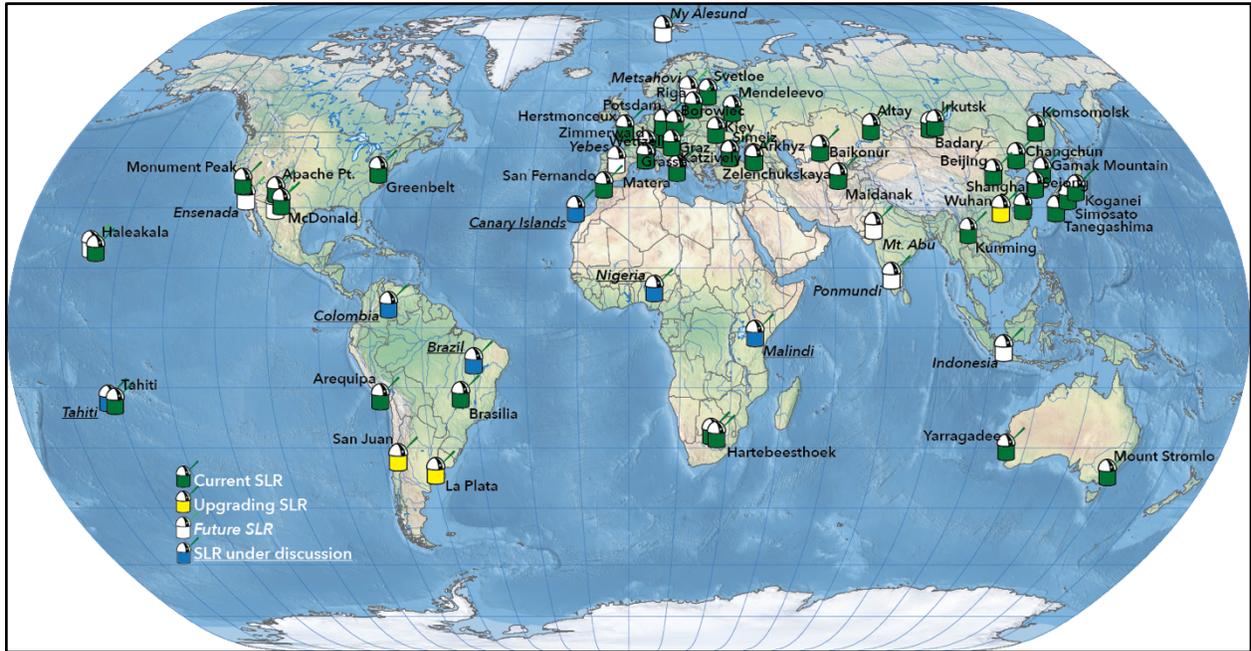


Figure 2. Global ILRS network of 39 operational laser ranging stations and planned new and upgraded locations.

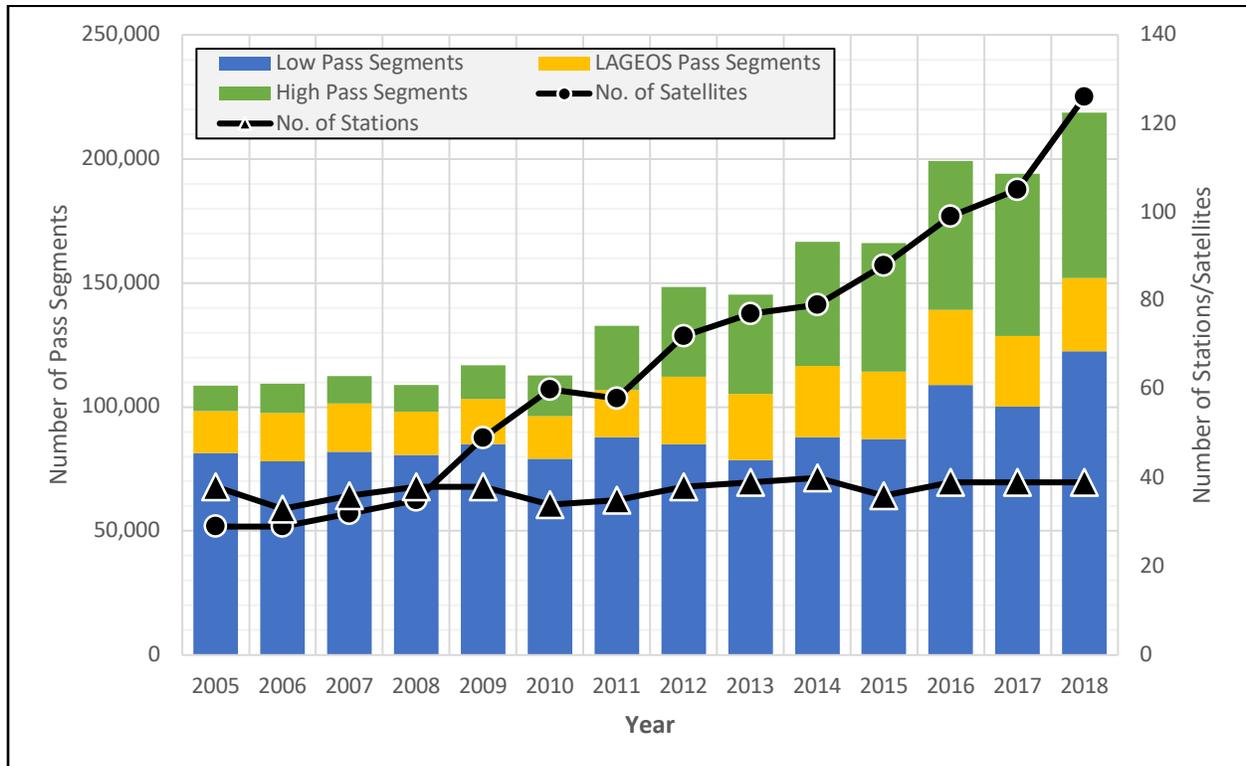


Figure 3. Chart showing pass segment totals vs. number of stations and number of tracked satellites. The total number of pass segments increased by nearly 15% in 2018 from the previous year.

Figure 4 shows one year of station tracking statistics for the period September 2017 through August 2018. As this figure shows, half of the stations in the ILRS network are at or near the 3500-pass minimum as specified in the ILRS guidelines. However, the figure also illustrates a large divergence in station performance. In some cases, a lower data yield can be attributed to station upgrades or technical issues. Unfortunately, many stations continue to perform at lower levels and thus make little contribution to ILRS derived products, which are required input for generation of the ITRF and other science areas.

The ILRS has also implemented revised application criteria for stations requesting participation in the ILRS network. Any new, or significantly upgraded, station requesting to join the ILRS network must follow recently updated operating guidelines, in particular:

- Range to satellites that have been authorized by the ILRS
- Adhere to the ILRS restricted tracking procedures
- Keep their site logs and configuration files current
- Maintain aircraft avoidance and other safety procedures
- Strive to produce the highest quality SLR measurements

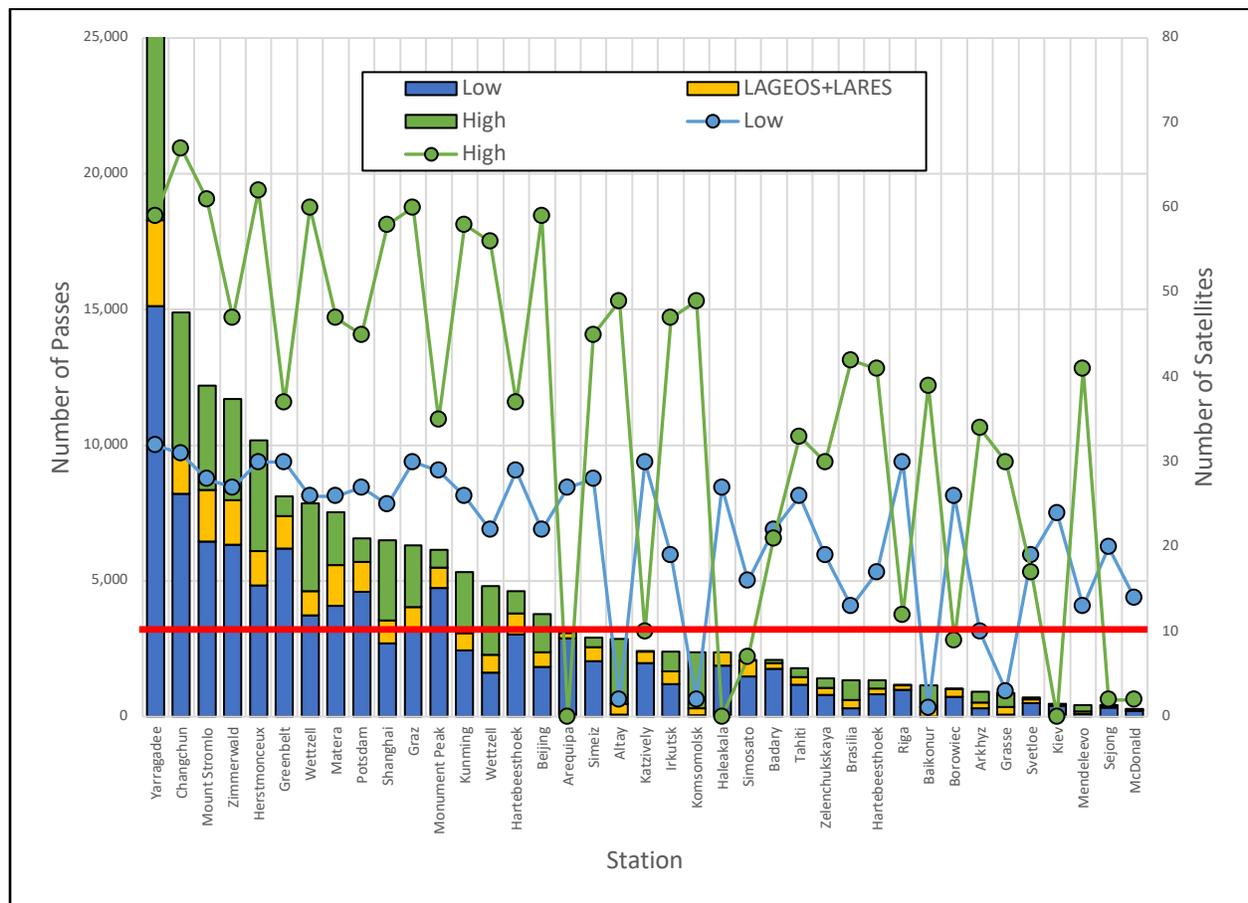


Figure 4. Twelve-month pass totals for stations in the ILRS network (September 2017 through August 2018). The horizontal red line shows the ILRS pass total (annual) guideline of 3500 passes.

5. Mission Support

The ILRS network supports scientific research through laser ranging to a variety of satellites equipped with reflectors (see Figures 5a-c). The ILRS provides tracking data support to different applications, such as geodetic (e.g., LAGEOS, LARES, Etalon, etc.), Earth sensing (e.g., Jason, GRACE, etc.), navigation (e.g., GLONASS, Galileo, Beidou, GPS, etc.), and experimental/special (e.g. cubesat missions, etc.). The tracking priority of supported missions is ordered according to satellite orbital altitude and special project needs. In 2018, an additional twenty satellites were added to the ILRS priority list, including newly approved missions (GRACE-FO, ICESat-2, PAZ, Sentinel-3B, HY-2B, and SNET) as well as additional satellites in the GNSS constellations (Galileo, Beidou, GLONASS, and IRNSS).



Figure 5a. GRACE-FO satellites
(image source: NASA)



Figure 5b. SNET satellites (image source: Technische Universität Berlin)

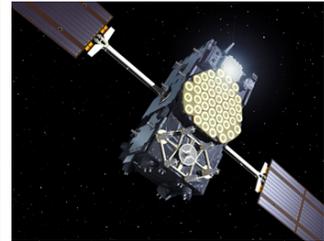


Figure 5c. Galileo satellite
(image source: ESA)

5.1. New Mission Support

New missions seeking laser ranging support, must complete and submit a New Missions Support Request form to the ILRS Central Bureau. After an initial review, the ILRS Central Bureau (CB) forwards a valid request to the Missions Standing Committee (MSC) for a more detailed evaluation. If accepted, the request is submitted to the ILRS Governing Board for acceptance as a future supported mission. During this process, the MSC carefully reviews the request considering several factors, including the likelihood of successful network support in meeting the mission's requirements, the timeliness of the request with respect to the future launch date, and that the goals of the mission and SLR tracking contribute to the mission of the ILRS. The ILRS MSC and CB recently updated the guidelines posted on the ILRS website for new missions seeking ILRS tracking support:

https://ilrs.gsfc.nasa.gov/missions/mission_support/new_mission_support.html

To better ensure success for the mission AND the ILRS, any group considering a request to the ILRS for laser ranging support must inform the ILRS well in advance of launch and, ideally, during the mission planning phases.

5.2. Tracking Campaigns

The ILRS CB organizes special dedicated campaigns to provide more intensive or increased tracking on select missions. GNSS tracking, in particular, has been a challenge which will only become more demanding for the network as additional satellites are launched in each constellation and as the GPS-III satellites equipped with retros are launched in the next few years. As shown in Figure 6, a number of stations in the network are successfully tracking the GNSS satellites; 14 stations produce 1000 or more passes per year, but stations in the Russian network

focused primarily on the GLONASS satellites. It should also be noted that the lower number of Beidou passes is due to their selection of geosynchronous satellites for SLR tracking, which are accessible by fewer stations in the network.

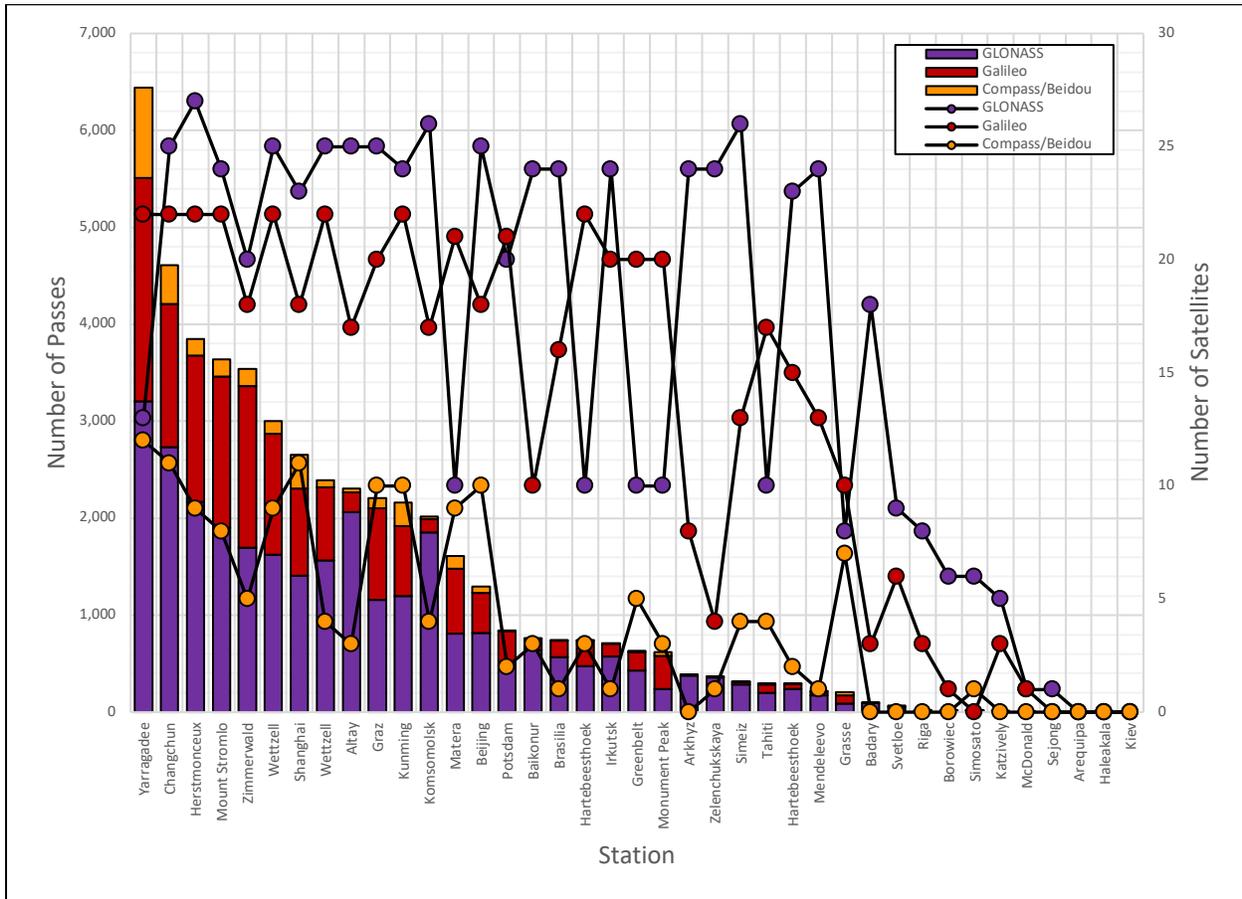


Figure 6. ILRS station performance: tracking of GNSS constellations (GLONASS, Galileo, Beidou), September 2017 through August 2018.

The ILRS is faced with different requests for GNSS tracking; some requesting intensive tracking on a few GNSS satellites and others requesting even sparse tracking on as many GNSS satellites as possible. The first type of request came from the missions; the second from the International GNSS Service (IGS) user community. Intensive tracking was characterized by three tracking segments of at least two normal points each, with the segments placed early, middle, and late in the pass. Sparse tracking was at the level of one segment per pass

In 2018, the ILRS conducted two “Laser Ranging to GNSS s/c Experiment” (LARGE) tracking campaigns, to examine how the service might combine the two options and address the needs of both communities.

- In the first campaign (February 15 through May 15, 2018), each GNSS constellation identified four primary and four secondary satellites for intensive tracking; during this campaign, only predictions for these 24 satellites were made available to the stations. In this first campaign, the primary satellites showed an increase in tracking coverage (more passes), however, stations still tracked many of the other GNSS satellites (stations used

predictions from other sources). Following the first campaign, it was apparent that although some stations provided adequate tracking coverage, there was an imbalance in the tracking coverage for the three constellations.

- In the second campaign (August 01 through October 31, 2018) Galileo and Compass/Beidou constellations selected eight satellites each for high priority tracking; GLONASS chose to identify only four. Since only four satellites were designated for GLONASS, the stations were instructed to try to obtain as many passes on these satellites as possible. Predictions for all the other satellites in each constellation were issued and thus stations could continue to track these satellites on a non-interference basis with the LEO, LAGEOS, and selected GNSS satellites at higher priority. The designated LARGE GNSS satellites were interleaved on the priority list to try to give each constellation an equal chance of tracking.

Data generated from the first 2018 LARGE campaign are summarized in Figures 7a and 7b. The LARGE campaigns have demonstrated that the ILRS can support intensive tracking of a selected number of high-priority GNSS satellites as well as reduced tracking on satellites at a lower priority in order to increase total data yield. Additional observations about the campaign can be found in the monthly reports from both 2018 LARGE campaigns available on the ILRS website:

https://ilrs.gsfc.nasa.gov/science/ILRS_LARGE_sg/LARGE_activities/LARGE_activities.html

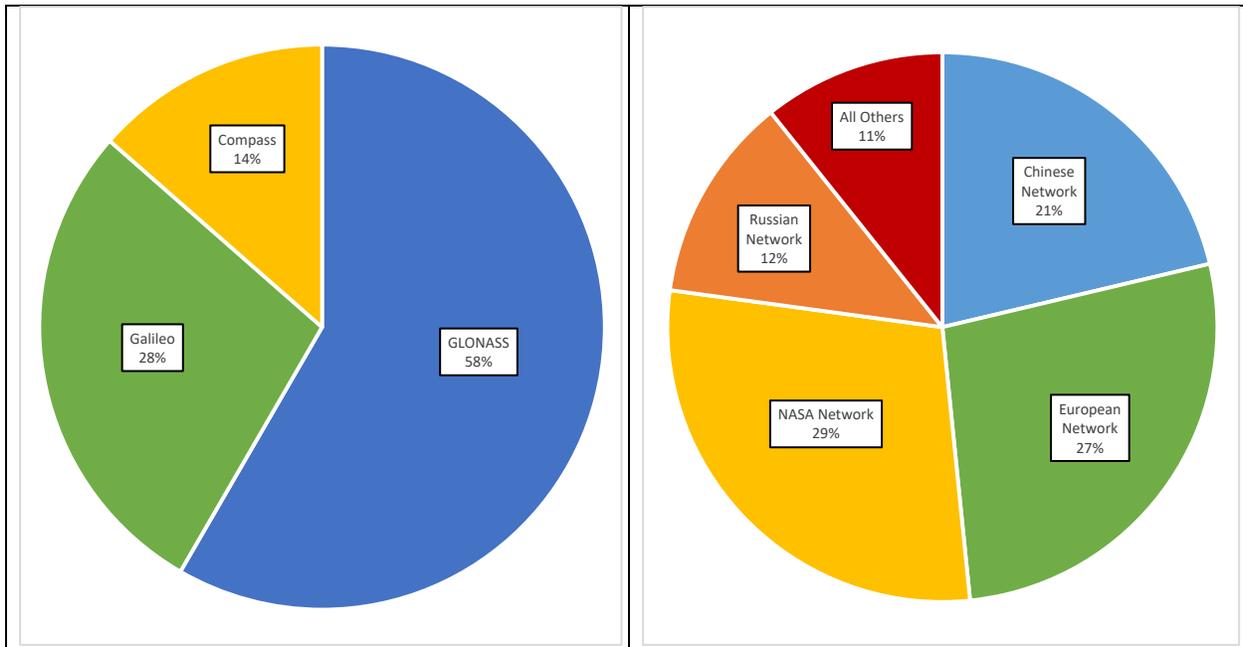


Figure 7a. 2018 LARGE Campaign 1 station tracking totals by GNSS constellation.

Figure 7b. 2018 LARGE Campaign 1 tracking totals by network. (Chinese network: 4 stations; EUROLAS network: 13 stations; NASA network: 8 stations; Russian network: 9 stations; Other: 2 stations).

A strategy under consideration for future GNSS tracking support could be based on four high priority satellites chosen by each constellation for intensive tracking and a pool from the remaining GNSS satellites for sparse tracking on a random basis by the station, with perhaps some guidance to avoid too much data on just a few satellites. Discussions will continue with the

GNSS missions and the other interested groups (e.g., the International GNSS Service/IGS and the International Committee on GNSS/ICG) to design the best future tracking scenarios for GNSS.

The Analysis Standing Committee (ASC) has requested that the ILRS organize a tracking campaign in 2019 to increase data volume on Etalon-1 and -2. This increased data yield would benefit the ITRF, particularly the determination of Earth Orientation Parameters (EOPs). During the proposed three-month campaign, stations will be asked to obtain at least one pass per day on each of the two satellites; passes should sample the Etalon orbits with three NPs early in the pass, three NPs at maximum elevation, and three NPs toward the end of the pass. The stations have been able to strengthen their ability to track satellites at GNSS altitudes so a campaign on the Etalon satellites should generate the amount of data required (about 20-30% of the LAGEOS data).

5.3. Restricted Tracking

The ILRS network also provides laser ranging support to satellites that must be tracked by stations following certain constraints or under certain conditions. These “restricted tracking” missions include satellites equipped with: 1) sensors that could be damaged if illuminated by a laser beam, 2) corner cubes that may not be visible under certain geometric conditions, or 3) detectors that only can handle a certain level of power produced by an SLR station. In order to support these missions, the ILRS, through the CB and MSC, must develop mission-specific procedures for restricting SLR tracking of vulnerable satellites; this process often takes considerable time, coordination, and interaction between the CB, the MSC, the mission, and the stations. The ILRS CB and MSC must ensure that the mission requirements are met in a safe manner and that all stations range to the satellite following established guidelines. The ILRS CB works with these missions requiring restricted tracking by providing station configuration information; the CB also interacts with the stations, coordinating how and under what conditions they can range to the satellite. Recent restricted tracking missions include the Sentinel-3 satellites and ICESat-2.

6. Central Bureau and ILRS Operations

6.1. Quality Control Board Activities

Following recommendations from the 19th International Workshop on Laser Ranging, the ILRS Analysis and Networks and Engineering Standing Committees (ASC and NESCE), in conjunction with the CB, established the Quality Control Board (QCB) to study SLR data quality issues including data biases and other systematic errors that are degrading ILRS data and derived products. The QCB meets via telecon on a regular basis. Recent accomplishments include routine generation of QC reports from ACs and AACs that visualize issues and communicate these issues to stations, and operational implementation of diagnostic procedures developed under the recently completed “Station Systematic Error Monitoring Pilot Project”. Results from some of these activities have led to additional systems characterization information being added to the revised SLR data format and adoption of a new approach in developing the official analysis products.

The QCB is currently examining consistency in the computation of normal points at the stations and the impact of some of the differences in calibration procedures. Summaries of QCB telecons and links to recent activities are available on the ILRS website:

<https://ilrs.gsfc.nasa.gov/science/qcb/index.html>

6.2. Assessing Station Performance

In order to emphasize the value of station performance to mission support and generation of the ILRS products, the ILRS regularly evaluates SLR data and station compliance with established standards. One example of this reporting is the monthly station report cards which tabulate twelve months of data quality, quantity, and operational compliance with the standards. The ILRS Central Bureau established a small team to investigate new methods for assessing station performance and providing additional reports to help stations see where they perform well and identify areas for improvement. These reports, which will soon be available on the ILRS website, also analyze station tracking capabilities, interleaving of satellite passes, compliance with the ILRS priority list, and number of normal points per pass. The network report cards, and future station assessment tools, are available on the ILRS website:

https://ilrs.gsfc.nasa.gov/network/system_performance/index.html

6.3. Data Screening

The NASA and EDC operations centers (OCs) worked with the ILRS CB and relevant standing committees (SCs) to develop improved data screening and quality control procedures on incoming data. Historically, the two ILRS OCs performed similar data checking on station data; these procedures were not identical and thus, on occasion, led to discrepancies in the data they submitted to the ILRS data centers. Thus, the OCs defined a set of standards on data content and format which will be implemented in the next year. This “standard QC” proposal is currently under review at the CB and the NESC and when in place at both the NASA and EDC OCs, will avoid these consistency problems and will improve the ILRS data and derived products.

6.4. Site Log Procedure and Format Updates

The Data Formats and Procedures Standing Committee (DFPSC) and NESC also worked on revisions to the ILRS site log format. The site log contains a historical collection of station information and system configuration parameters; the logs are an important tool for users when analyzing SLR data. Modifications to the format include documenting restricted tracking capabilities, retention of historic survey information, additional ground target and calibration information, laser beam divergence data, and other changes to clarify data entries. In addition, the EDC developed a web tool for updating and maintaining the site log; the new procedures should make the update process easier for stations, thus ensuring logs are current, an essential requirement for the user community. The ILRS plans to put these new procedures for updating and submitting site logs in place over the next few months.

6.5. Data and Prediction Format Updates

The DFPSC recently developed the first significant revisions to both the Consolidated Range Data (CRD) format and the Consolidated Prediction Format (CPF). The initial versions of these formats were developed and implemented over a decade ago to provide a more flexible method for distribution of data and laser ranging predictions. The SC developed the specifications for Version 2 primarily to address requirements of future missions (e.g., the European Laser Timing, ELT) and applications (e.g., space debris tracking); furthermore, the revised formats provide ways to capture additional information and correct issues that have been identified. The SC coordinated

these revisions with the ILRS infrastructure (operations centers, data centers, analysis groups, and stations) and updated documentation on the ILRS website:

https://ilrs.gsfc.nasa.gov/data_and_products/formats/index.html

Testing of these format revisions within the ILRS infrastructure is now underway.

7. Concluding Remarks

Although there has been much progress in the ILRS in recent years, issues and challenges remain for the service. The network continues to grow and improve, but major gaps in geographic coverage remain, particularly in Latin America, Africa, and ocean regions. Some of these gaps will be addressed over the next few years as new stations come online and new partnerships are formed. The lack of standardization in system hardware and operations remains an issue, but agencies are implementing new hardware that should improve commonality. Data quality issues remain but several standing committees, analysis centers, and the QCB are working to identify ways to detect and reduce systematic errors. As the number of satellites requesting support continues to grow, the ILRS needs to implement more effective tracking strategies as well as conduct periodic user community surveys in order to better understand requirements.

References

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- Beutler, G. and R. Rummel (2012), Scientific rationale and development of the Global Geodetic Observing System, in International Association of Geodesy Symposia, Volume: 136, pp. 987-993, S.C. Kenyon, M.C. Pacino, U.J. Marti editors, Springer-Verlag, doi: 10.1007/978-3-642-20338-1_123